Post-test noise predictions for a low-speed fan stage with inflow distortion

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Introduction

In future aircraft concepts, engines may be exposed to strong inflow distortions due to boundary layer ingestion or short intakes. In this context, the aeroacoustic effects of different inflow distortions were investigated at the low-speed ducted fan test rig CRAFT [1, 2, 3]. With the aim to include noise predictions in the process of distortion-tolerant fan design, post-test predictions of the experiments are conducted using the physics-based fan noise prediction method of Staggat [4]. The method has recently been applied for post-test predictions of a propeller ingesting a boundary layer [5, 6].

Experimental Setup of the Co-/Contra Rotating Acoustic Fan Test rig CRAFT

Measurements were conducted in the CRAFT rig using the reference fan with B=18 rotor blades, V=21 stator vanes and a constant duct diameter of 453.6 mm. The inlet was equipped with an inflow control device (ICD) to ensure a homogeneous and low-turbulence reference inflow-field. Distortion screens were mounted in the inlet on top of a structural honeycomb, as shown in Fig. 1, left. The impact of the distortion screens on the mean and turbulent inflow components was measured in a plane about one diameter downstream of the honeycomb and one diameter upstream of the rotor (Fig. 1, center). Acoustic measurements in the inlet were performed with a stepwise traverse line array comprising 30 microphones combined with a fixed circumferential array of 59 microphones (Fig. 1, right). The microphone array in the outlet section consisted of 22 axially and 29 circumferentially positioned sensors (not shown). Further details of the setup are given in [1, 2, 3].

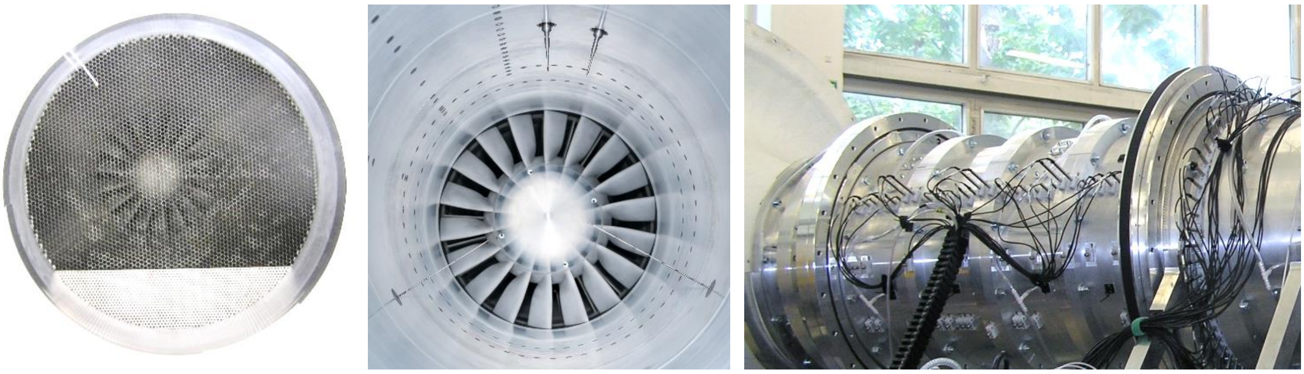

Fig. 1 Photographs of components of the experimental setup of the CRAFT rig, inlet distortion screen, aerodynamic measurement probes (hot-wire probes and total pressure rakes) and inlet microphone arrays.

Fan noise post-test-prediction method

Two broadband noise sources are modelled: The broadband rotor-stator interaction (RSI) noise and the broadband inflow-rotor interaction (IRI) noise. Both broadband noise sources arise from the unsteady lift forces that result from the turbulence in the inflow and rotor wakes, respectively. For the prediction of the broadband IRI turbulence information obtained from hot-wire measurements upstream of the rotor is used as input (Fig. 2, center. The axial velocity component is shown). The prediction of the broadband RSI noise was lately performed by Karasu [7], using the measured rotor wake turbulence downstream of the rotor for clean inflow conditions (Fig. 2, right).
The tonal RSI noise is modelled as unsteady loading noise with a dipole characteristic. The velocity deficit in the rotor wakes leads to periodically fluctuating forces on the stator vanes. The excited noise propagates in the form of a few specific modes. The mean velocity-field downstream the rotor is extracted from the hot-wire measurements (Fig. 2, right). The tonal IRI noise is modelled similarly, but in this case the fluctuating forces on

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the rotor blades are a result of the non-homogeneous inflow (Fig. 2, left). The excided modes depend on the harmonic components of the mean flow and the number of blades [3, 4].

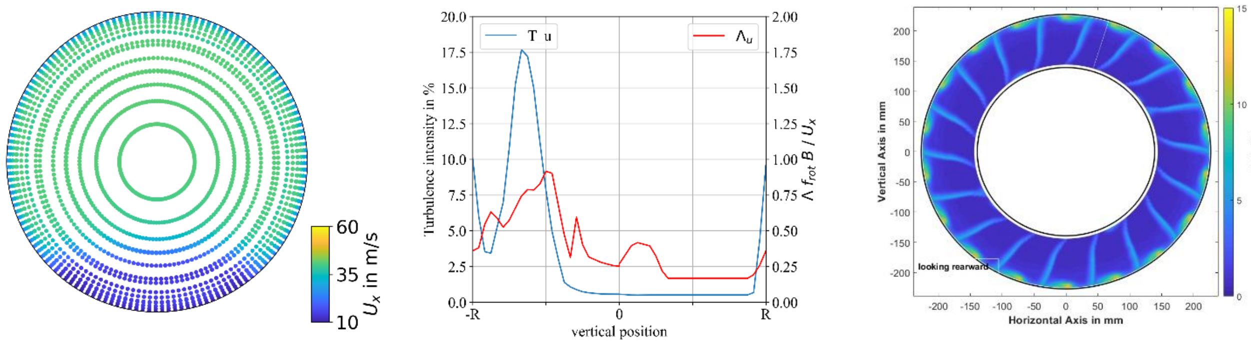

Fig. 2 (left) mean axial velocity upstream of rotor for the case with distortion device from Fig. 1 measured by means of total pressure rakes; (center) axial component of the turbulent intensity T_u and length scale Λ_u upstream of rotor for distorted flow; (right) turbulent intensity downstream of rotor, measured with hotwire anemometer for clean conditions.

Preliminary results

Fig. 3 shows preliminary results of the ongoing study. The broadband noise (Fig. 3, left) is predominantly increased for low frequencies by the inflow distortion both in the experiment and in the prediction results. However, the hump around 1 BPF is not reproduced by the prediction method. Also, a larger deviation between up- and downstream sound radiation is observed in the experimental and IRI results. One reason for the smaller gap in the modelled RSI data is the omission of rotor shielding.

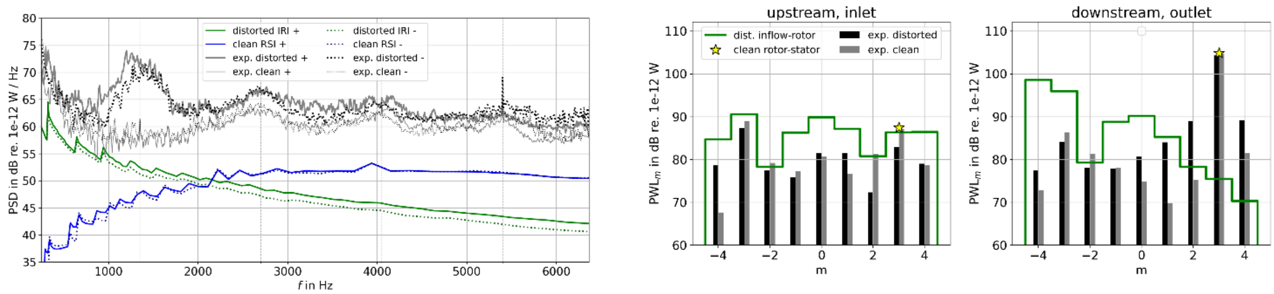

Fig. 3 Results of inflow distortion noise measurements and prediction at design operating condition: (left) broadband results: Solid lines mark downstream propagating sound power in the outlet and dotted lines mark upstream propagating sound power in the inlet; (right) sound power level of the azimuthal modes at BPF.

The tonal RSI modes are well reproduced for clean inflow condition, see exemplarily m=3 at BPF in Fig. 3 right. Note that because of the mode propagating orthogonal to the stator blade angle in upstream direction, the interaction mode m=3 is weakly excited in the upstream direction. The tonal inflow rotor interaction noise in green is overestimated by the prediction method compared to the experimental results. The reason for this is still under investigation. Possible reason could be the uncertainties in the mean flow measurement and in the propagation of the measured flow-field to the rotor leading edge. An interpretation of the measured tonal components is difficult as both noise sources are superimposed. The measured increase of modes adjacent to the RSI mode m=3 in the outlet could due to a modulation of the rotor wakes as well as be the scattering effect due do mode propagation through the non-homogeneous inflow.
The final presentation will include further results of the measurements and post-test predictions. A variation of operating conditions and distortion screens will be analyzed to allow trend studies.

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